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HIGH SENSITIVITY - LOW CAPACITY LOAD CELL WITH OVERLOAD PROTECT--ETC(U)
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HIGH SENSITIVITY - LOW CAPACITY LOAD CELL WITH
OVERLOAD PROTECTION

WESTINGHOUSE ELECTRIC CORP
ADVANCED ENERGY SYSTEMS DIVISION
PITTSBURGH, PA 15236

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August 1979

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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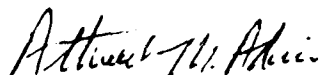
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Project Engineer
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FOR THE COMMANDER


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Chief, Processing and
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Research in metalworking frequently requires utilization of a small fraction of the load capacity of the equipment. This situation can result from small work-pieces because of limited amounts of experimental materials, prior deformation processing of ignots or constraints on experimental variables. Measurement of small loads can pose linearity and sensitivity difficulties when using load cells designed to accommodate full press capacity. A high sensitivity		

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low capacity load cell was designed with a load measuring capability up to 110,000 lbs and capable of safely accommodating loads up to maximum press load (1.1×10^5 lbs).

The load cell was built, instrumented with strain gages and calibrated up to 200,000 lbs on a certified testing machine. Flow stress-strain curves obtained from loads measured using the cell are shown.

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FOREWORD

This report was prepared by Ivan A. Martorell, Materials Laboratory, Metals and Ceramics Division, Wright-Patterson Air Force Base and F. J. Gurney, Westinghouse Electric Corporation, Advanced Energy Systems Division, under Project No. 2418, Task No. 241804. The overall effort is included under USAF Contract No. F33615-74-C-5059, "Processing of Metals". The Air Force contract was administered under the direction of the Metals and Ceramics Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio with Mr. A. M. Adair (AFML/LLM) as the Air Force Project Engineer.

This report covers work performed from March 1975 to May 1979 at the Air Force Materials Laboratory (AFML/LLM), Wright-Patterson Air Force Base, Ohio.

This report was submitted by the authors on August 25, 1979, and in revised form on 2 October 1980.

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SECTION I

INTRODUCTION

Research in metalworking realistically favors use of production rated equipment for experimental processing. Because of the limited amounts of experimental materials and because of prior primary deformation processing of experimental size ingots, the size of experimental workpieces are frequently small. The deformation loads on these small workpieces are only a small fraction of the total press capacity. Measurement of these small loads can pose a difficulty when using load cells designed to accommodate full press capacity. The prime source of the problem results from the non-linear response of high electronic amplification of the small signals produced from very small non-uniform elastic deformations. The condition outlined above occurs frequently during experimental metal processing operations at the Air Force Materials Laboratory and can be expected to occur elsewhere as well.

SECTION II

EXPERIMENTAL REQUIREMENTS

The use of a low capacity high sensitivity load cell arises frequently during flow stress determination under forging conditions using the ring compression test. The usefulness of this type cell is particularly valuable at conditions that result in low loads, for example when the forging is done at higher temperatures or lower speeds, with small samples. The case considered here is for Ti-10V-2Fe-3Al rings forged isothermally at 1250°F, 1350°F and 1450°F, at two speeds, 0.03 ipm and 3.0 ipm. The material used had a grain size of 8 μ m. The rings were 0.4 inches thick with 1.200 inches outside diameter and 0.600 inches inside diameter. The details of the ring compression test are found elsewhere(1-5).

The forging press used was the 500 ton Lombard Hydraulic Press at the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. The load cells normally used with this press can safely measure loads in excess of 700 tons with a reasonable sensitivity of 0.07 mv/ton and linearity from about 25 tons. These load cells on hand were inadequate for the low load measurement requirements of 1 to 40 tons required by the material, grain sizes, specimen geometry and forging conditions selected. These workpiece and processing conditions dictated that a new load cell be designed which would meet the following requirements:

- 1) A load measuring capability up to approximately 55 tons.
- 2) A sensitivity of approximately 0.5 mv/ton (about 7 times the sensitivity of the load cells available).
- 3) A linear output in the load range of 0 to 55 tons would be ideal, a monotonically increasing output voltage-load relation up to 2 or 3 tons and linear output up to 55 tons would be acceptable.
- 4) A capability to take full press load without damage.

SECTION III

PRODUCT DESIGN

The load cell, designed to satisfy this requirement, consisted of two parts: A high sensitivity section to measure the load up to 55 tons and an overload section to carry the load in excess of 55 tons and insure that the deformation of the high sensitivity section remained in the elastic region at maximum press load. The design developed to incorporate both of these functions consisted of a thin-walled outer sleeve as the high sensitivity section and a solid inner core as the overload section. These requirements were obtained by designing the thin-walled measuring sleeve to be slightly taller than the overload protection solid inner core. This design insured that during initial deformation no load would be absorbed by the inner solid core. The design selected is shown in Fig. 1.

The geometry of the new load cell was chosen based on the dimensions of the cells on hand. An outside diameter of 5.00 inches and an inside diameter of 4.80 inches were chosen for the thin-walled measuring sleeve. These dimensions would minimize modifications to the equipment with increased sensitivity as compared to the cells being replaced. The material chosen was H-12 tool steel. This material was selected because of its high yield strength (in excess of 200 ksi) with good strength at slightly elevated temperatures. In addition this material was successfully used for the load cells on hand and it was already available.

The total deformation and load seen by the measuring sleeve at maximum press load were minimized by selection of the dimensions for the solid inner core overload section. An outside diameter of 4.560 inches was selected for the inner core. The area of the measuring cell was minimized (See Fig. 2) to obtain maximum elastic strain (sensitivity and linearity) but still maintain a reasonable safety factor. The deformation and load at the yield point of the material were recalculated for the optimum area. Tolerances in the dimensions of the load cell were chosen so that the resulting dimensions would be bounded by the two conditions considered; initial and optimum dimensions (Details of the design calculation were included in the Appendix). The final specifications for the load cell components are shown in Fig. 2.

The design height of the measuring sleeve was 1.990 inches and the outside diameter was 5.0 inches. With the height of the solid core overload section 0.00400 inches shorter than that of the measuring sleeve the first 80,800 lbs. of load are applied only to the sleeve. At this time both the sleeve and solid core will be the same height. An increase in load over 80,800 lbs. would then be proportioned between the sleeve and solid core based on their cross-sectional areas. The high sensitivity measuring sleeve was instrumented with resistance strain gages. Eight 120 ohm - 0.250 gage length strain gages were used.

The load cell was calibrated on a certified testing machine from 0 to 200,000 lbs. A 12 VDC powder supply was used for excitation of the Wheatstone Bridge and a Digital Voltmeter was used to measure the output voltage. The load-output voltage calibration data for the load cell is shown in Fig. 3A for the load range 10,000 to 200,000 lbs and in Fig. 3B for the load range 400 to 25,000 lbs.

Three load ranges are identified in the calibration of the load cell: low, medium and high load regions. Each region is characterized by a linear relationship between load and output voltage. The transition from the low load region (400 lbs to 1880 lbs, 0.26 MV to 1.116 MV respectively) to the medium load region (1880 lbs to 77220 lbs, 1.116 MV to 31.403 MV respectively) is a result of a non-uniformity of deformation resulting from very low loads.

The transition from the medium load region to the high load region depends on the actual gap existing between the measuring sleeve and the solid core, in the direction of the load application. When the gap is exhausted a percentage of the load is not applied to the measuring sleeve but to the solid core. The actual gap existing depends on the load required per 0.001 inch deformation of the sleeve and of the solid core.

Sleeve

Solid Core

$P/\Delta = 20217 \text{ lbs/mil}$

$P/\Delta L = 235620 \text{ lbs/mil}$

The transition from the medium to the high load region from the calibration data occurred at 77200 lbs. From this load and the $P/\Delta = 20217 \text{ lbs/mil}$ for the sleeve a gap of 3.8 mil is calculated which is in agreement with the actual measured gap of approximately 4 mil.

Loads in excess of 77200 lbs are partitioned to the sleeve and to the solid core in proportion to their P/Δ values: 7.9% of the load in excess of 77200 lbs is applied to the sleeve, the remaining 92.1% is applied to the solid core.

The error in the equation fitted to calibration data is less than 1.25% throughout the load range except at the transition from one range to another. The maximum error, calculated at the transition between the medium to the high load region, is less than 3.5%. The transition between the low and medium load region shows the error is less than 3%.

SECTION IV

APPLICATION

A set of stress-strain curves obtained for Ti-10V-2Fe-3Al are shown in Fig. 4. The loads used to calculate the flow stresses were measured using the low capacity high sensitivity load cell. The flow stresses were calculated using the particular ring test analysis in Ref. 5. The stress strain curves shown in Fig. 4 exhibit both softening and hardening, both resulting from rearrangement in the microstructure as a consequence of the hot working conditions used.

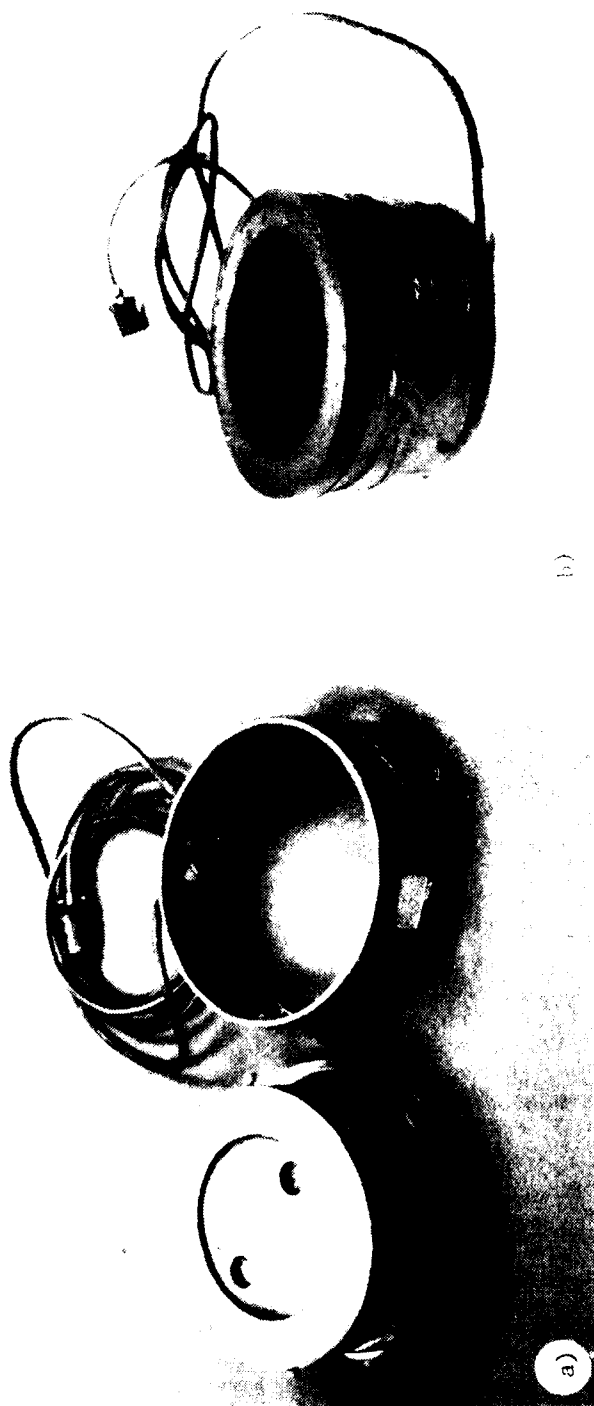
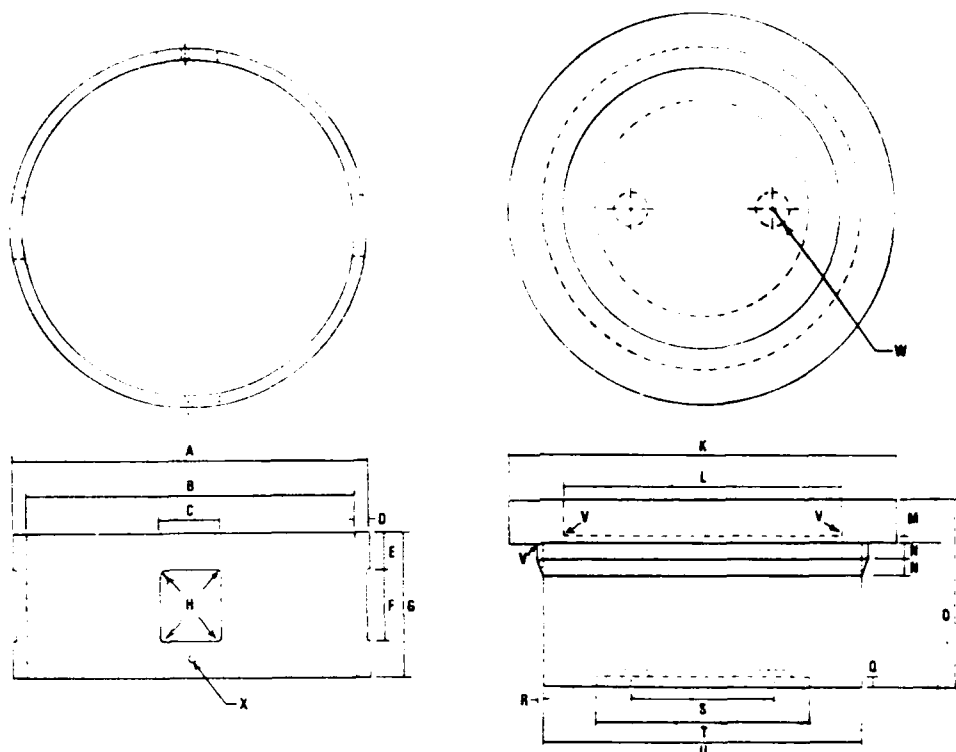


Fig. 1. Photograph of the high sensitivity load cell showing a) the strain gaged sleeve and the solid core overload section (note the solid core overload section is shown upside down) and also showing b) the assembled sections in the operational arrangement.



MEASURING SLEEVE

A = $5.000 + 0.010 - 0.000$
 B = 4.800 REF
 C = $0.870 + 0.000 - 0.005$
 D = $0.100 + 0.002 - 0.000$
 E = $0.500 + 0.005 - 0.005$
 F = $1.000 + 0.000 - 0.005$
 G = $1.990 + 0.001 - 0.001$
 H = 0.125 to 0.250 radius
 X = 1/8 dia. See Note 5
 K = $5.250 + 0.010 - 0.010$
 L = $3.875 + 0.005 - 0.005$

SOLID CORE

M = $0.510 + 0.005 - 0.005$
 N = $0.220 + 0.020 - 0.020$
 O = See Note 4
 P = $2.600 + 0.005 - 0.005$
 Q = $0.125 + 0.005 - 0.005$
 R = $0.085 + 0.005 - 0.005$
 S = $2.000 + 0.005 - 0.005$
 T = $3.000 + 0.000 - 0.010$
 U = $4.560 + 0.010 - 0.000$
 V = 0.625 radius
 W = 17/32 dia. X 3/16 deep two places

1. All dimensions are in inches.
2. Material: H-12
3. Edge to edge across P, G and O parallel to within 0.001 TIR.
4. Machine the sleeve and measure the dimension G to the nearest thousands. Calculate $O = (G - 0.006) + 0.001 - 0.000$.
5. Place the solid core inside the sleeve so that U fits inside B. The clearance between the solid core and the sleeve will be as specified in Note 4. The safety block may be rotated to insure an uniform clearance. Drill the two holes (X) thru the sleeve 1/4 inch from the bottom surface centered under rectangular hole and 180° apart. These holes will align with two threaded holes in the solid core (#5 (0.125) - 40 UNC X 3/8 deep). Two shoulder bolts will fit loosely (0.005 clearance) thru the holes in the sleeve and threaded into the solid core. The length of the shoulder will space the diameters of the core and sleeve without straining the measuring sleeve.

Fig. 2 Specifications of the load cell showing the two components, measuring sleeve and solid core.

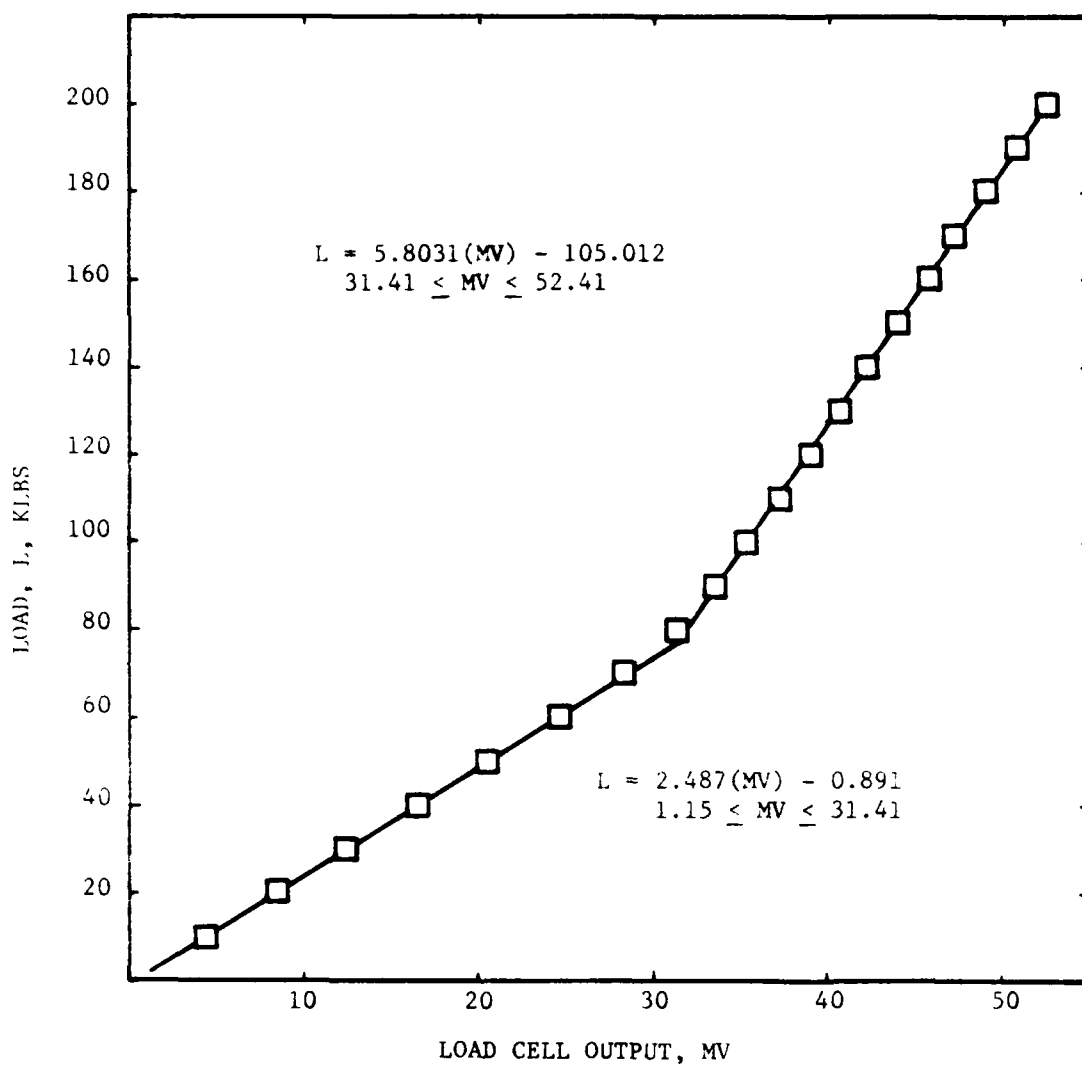


Fig. 3A Calibration curve for the load cell from 10,000 lbs to 200,000 lbs.

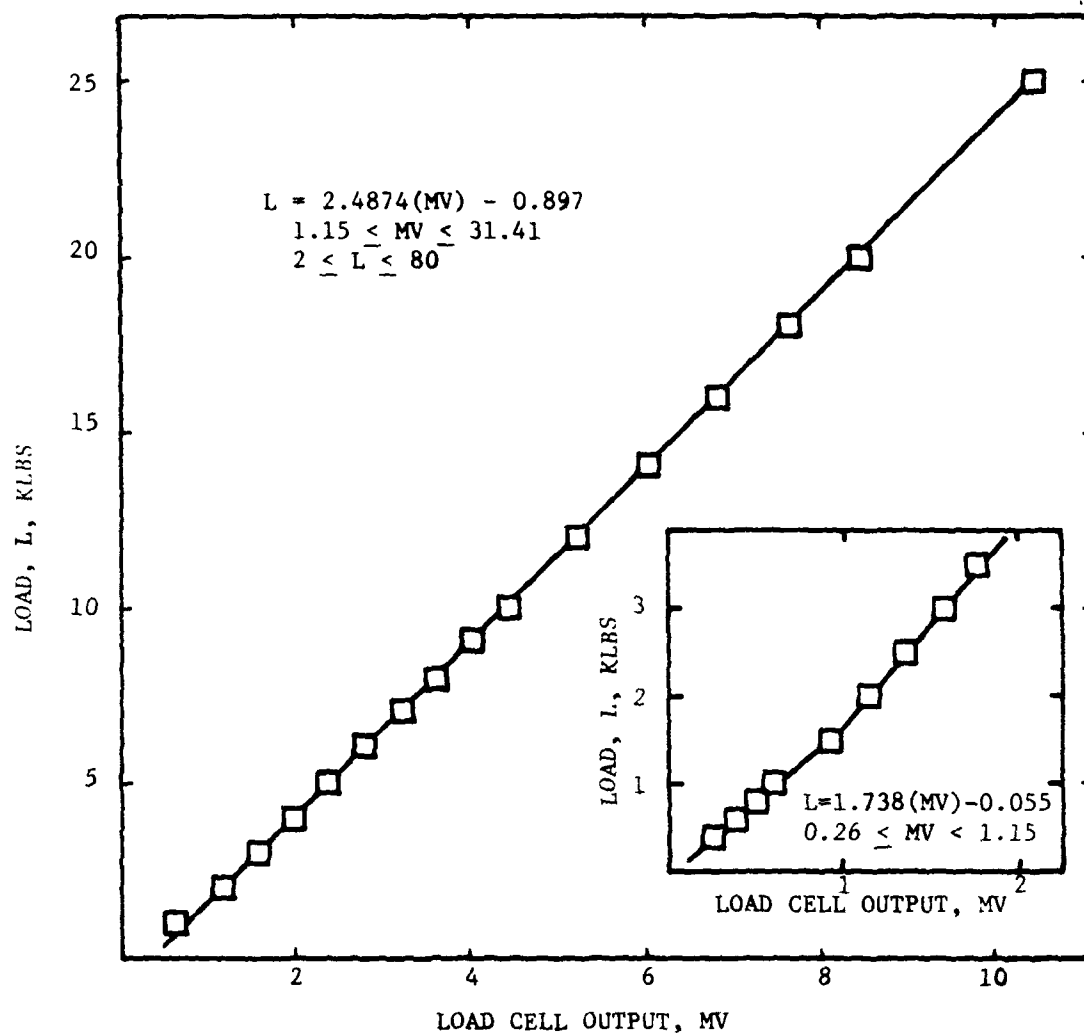


Fig. 3B Calibration curve for the load cell from 400 to 25,000 lbs.

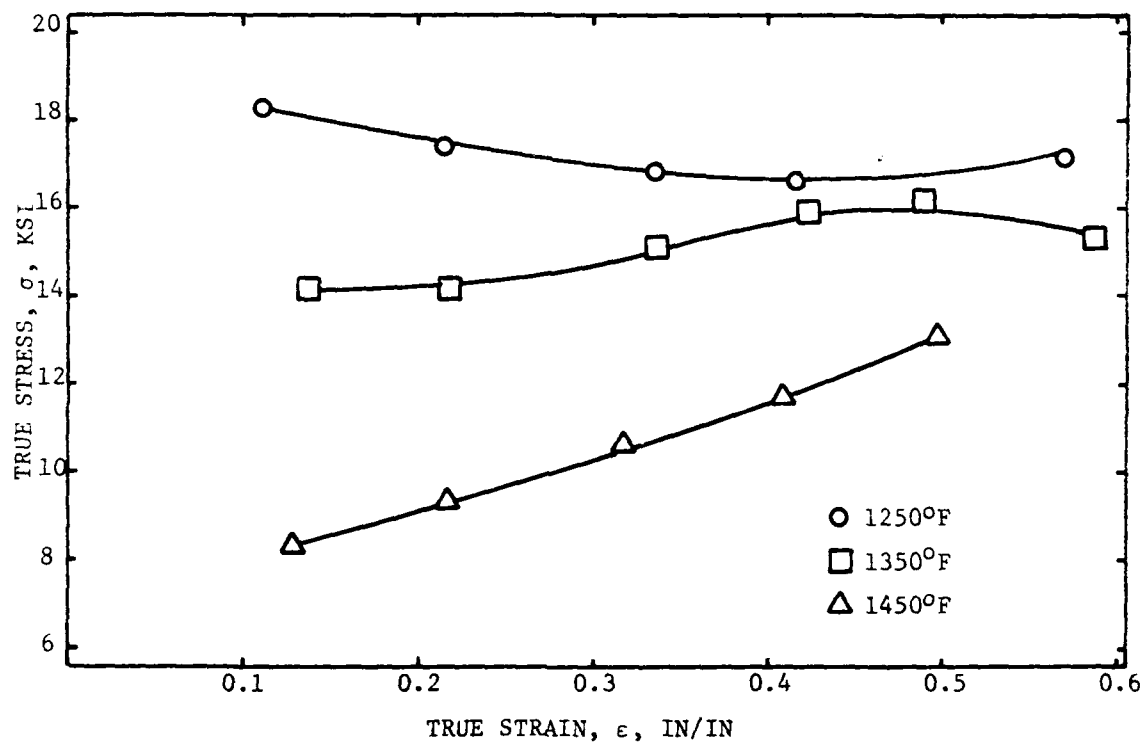


Fig. 4A Flow stress-strain curves for Ti-10V-2Fe-3Al (8 μ m) forged isothermally at 0.03 ipm and various temperatures. Forging loads used for flow stress calculations⁽⁵⁾ were measured using the low capacity high sensitivity load cell.

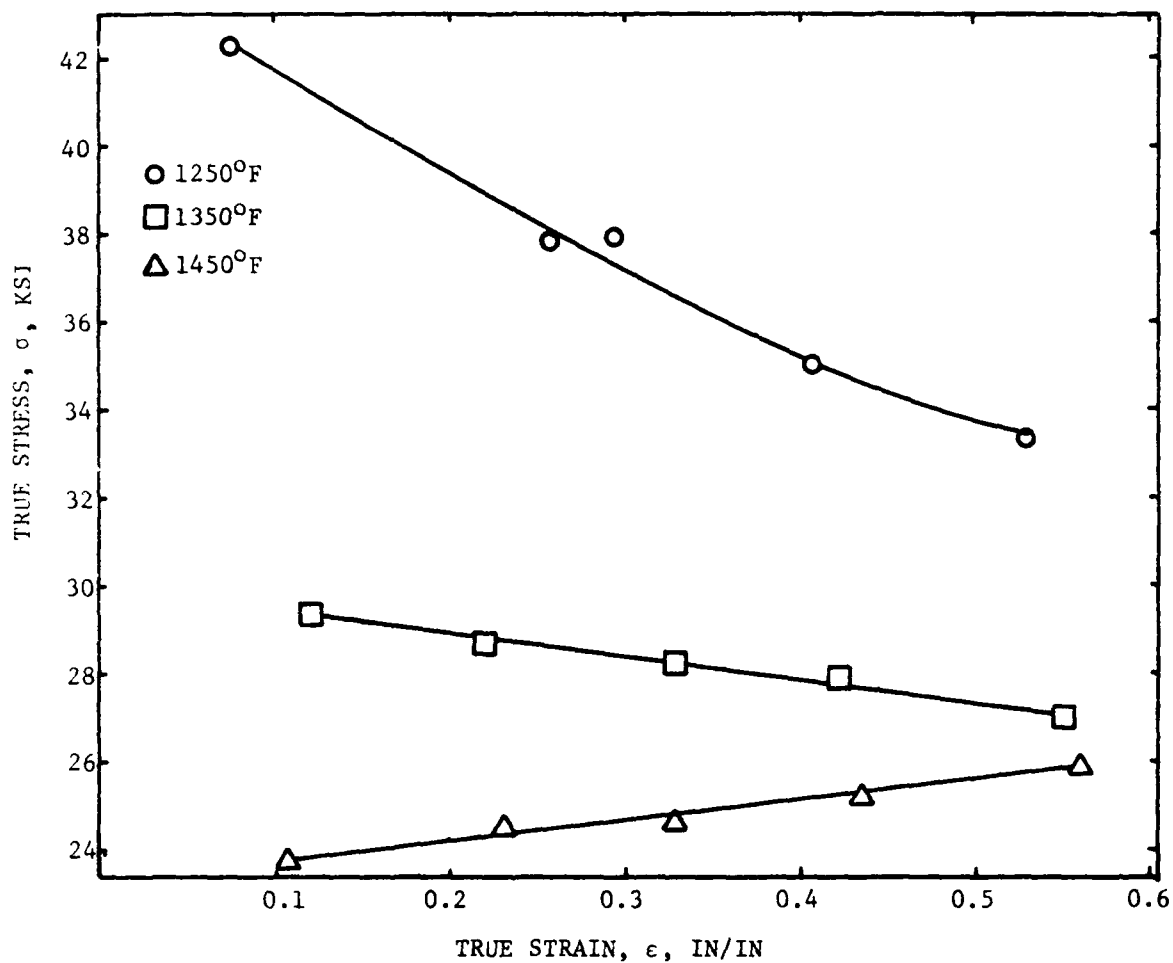


Fig. 4B Flow stress-strain curves for Ti-10V-2Fe-3Al (8 μ m) forged isothermally at 3.0 ipms and various temperatures. Forging loads used for flow stress calculations(5) were measured using the low capacity high sensitivity load cell.

APPENDIX

DETERMINATION OF THE DIMENSIONS FOR THE LOAD CELL COMPONENTS

The original dimensions of the measuring sleeve were selected to minimize changes to the forging equipment. The dimensions used were:

Outside Diameter	5.000 in.
Inside Diameter	4.800 in.
Height	2.00 in.

Based on these dimensions, on a yield strength of 2×10^5 psi and on a modulus of elasticity of 30×10^6 psi, the load and changes in height of the sleeve at the yield point were calculated:

$$P_{syp} = 307.9 \times 10^3 \text{ kbs,}$$

$$\Delta L_{syp} = 0.01333 \text{ in.}$$

With a clearance between the sleeve and the core of 0.120 inches, the cross-sectional area of the core becomes 16.33 square inches. The load and change in height for the sleeve and core were calculated at the maximum forging load of 1.1×10^6 lbs to be:

Sleeve	Core
$P_{sm} = 195.3 \times 10^3 \text{ lbs.}$	$P_{cm} = 904.7 \times 10^3 \text{ lbs.}$
$\Delta L_{sm} = 0.00846 \text{ in.}$	$\Delta L_{cm} = 0.00369 \text{ in.}$

Comparing ΔL_{syp} to ΔL_{sm} shows that only 63.5% ($8.46/13.33$) of the deformation at yield being utilized. The probable sensitivity and linearity of the cell was maximized by calculating the area required for 80% of the deformation at yield under maximum press load. The required deformation at maximum load then became $\Delta L'_{sm} = (0.01333)(0.8) = 0.01066 \text{ in.}$ In order to maintain a safety margin, $\Delta L'_{sm} = (0.010)$ was selected.

The deformation at yield was increased from 0.00846 to 0.010 in. by reducing the area of the sleeve. Since the area, load, modulus, height and change in height are related by

$$\Delta L = \frac{PL}{AE}$$

substituting the values for E, L, ΔL and for the load seen by the sleeve at maximum press load { $P_m = [1.1 + 9.5A/(16.33 + A)] \times 10^5 \text{ lbs.}$ }, an equation in terms of the area of the sleeve was obtained.

$$105A = 110 + \frac{990A}{16.33 + A}$$

Solving for A results in a cross-sectional area for the sleeve of

$$A = 1.1771 \text{ in}^2$$

The area of the sleeve was reduced to approximately this value with four rectangular holes machined equally spaced around the circumference of the sleeve in the center of the 2 inch height. Reducing the area in this fashion allowed a wall thickness of 0.100 inches to be maintained in the sleeve. The dimensions selected for the holes were 7/8 inch wide by 1 inch high.

The clearance in the height between the sleeve and core, required for 110,000 lbs measuring capability was calculated as:

$$\Delta L = \frac{1.1 \times 10^5}{30 \times 10^6} \cdot \frac{1}{1.5394} + \frac{1}{1.1894} = 0.00546 \text{ in.}$$

With this clearance all the load up to 110,000 lbs will be applied only to the measuring sleeve. Any load in excess of 110,000 lbs would be divided between the sleeve and core in proportion to their cross-sectional areas.

The load and height change of the sleeve at the yield point becomes

$$\begin{aligned} P_{sm} &= 1.85 \times 10^5 \text{ lbs.} \\ \Delta L_{sm} &= 0.00919 \text{ in.} \end{aligned}$$

$$\begin{aligned} P_{cm} &= 0.15 \times 10^5 \text{ lbs.} \\ \Delta L_{cm} &= 0.00373 \text{ in.} \end{aligned}$$

Complete cell specifications are shown in Figure 2.

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